A simulation of the transit network of the Paris Metropolitan Region with CapTA model

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Chapter 11: A simulation of the transit network of the Paris Metropolitan Region

1 Introduction

Once the transit assignment model is described and its behaviour is tested in simple networks, we wish to implement it in a large-scale network. Paris, capital of France, and the Ile-de-France region cover an area of 12 072 km2 and accommodate a population of 11,7 million (INSEE, 2012), making it an ideal field of application.

From the opening of the first metro line in 1900, an extensive public transportation system has been built, with a diversity of competing and complementary transit modes; boat, coach, buses, light rail, metro, RER and commuter rail. With 41 million daily trips by all motorized and non-motorized transport modes, the adequacy of the transportation system is crucial. However, the population boom and transport policies favourable to public transportation have put the transit system under pressure, while the saturation of some of its elements make the travel conditions intolerable (Le Figaro, 2010).

The analysis of the results does not pretend to be a diagnosis of the state of Greater Paris transit network. It rather acts as a showcase for the simulation capabilities of the CapTA simulator on a large scale network and as a means further investigate its behaviour. In addition, the results have served in order to elaborate some indicators for the travel conditions on the network.

The chapter is articulated in 8 parts and a conclusion. Firstly, we present the transport demand and the transit supply of the application field, the Greater Paris Area. In section 4 the model variants as well as the simulation parameters and characteristics are described. Thereafter, sections 5-8 present the results from the simulations and the comparison among the model variants. The passenger flow and the traffic state are dealt in section 5. The effect of the passenger flow on the transit operation is treated in section 6. Finally, sections 7 and 8 deal with the impact of the capacity effects and the comfort on the passengers. We conclude by stating the main advantages of the CapTA model and some appreciation of further development.

2 The Transport Demand in the Greater Paris

Along with its big population, the Greater Paris accommodates massive transport flows. According to the last global survey – EGT 2010 – (OMNIL, 2012), in 2010 we observed 41 million daily trips by all transport modes (not-motorized and motorized) of which 39% were pedestrian trips. The public transportation was involved in 34% of the motorized trips, with significant spatial diversity, whether the trip has an origin or destination at the centre of the agglomeration or not. In Figure 1, the modal shares are illustrated for the motorized trips by geographic relation. While, for the suburbs trips, the car captures nearly 80% of the motorized trips within Paris (*intra-muros*) and for the radial trips – where Paris is at one end – public transportation captures over 70% of the volume, due to a denser network and a greater efficiency compared to car.

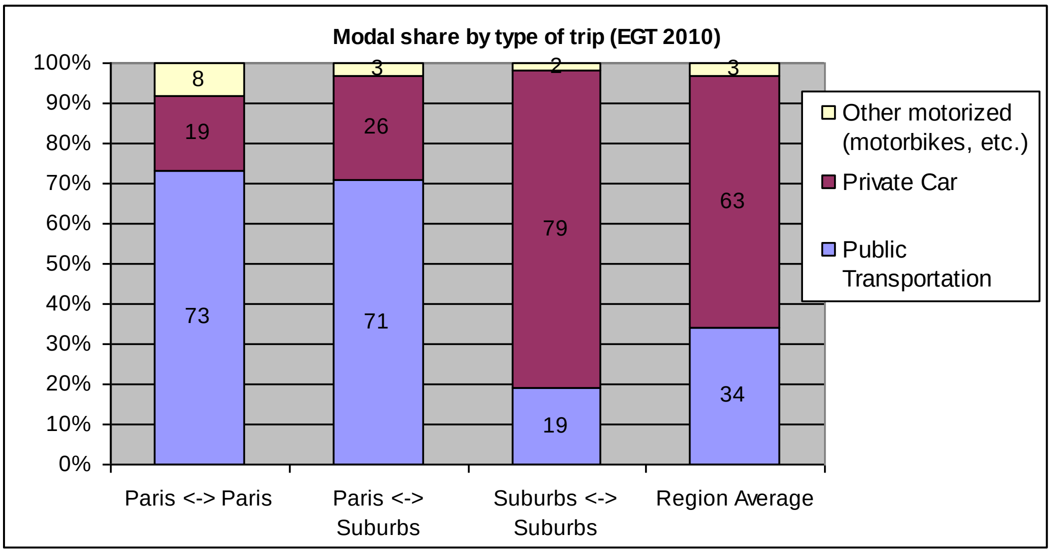

Figure 1 Modal Share of motorized trips by geographic relation (source: OMNIL, 2012)

The simulation of the Great Paris Region concerns exclusively the public transportation modes. Our input consists of the data distributed by the DRIEA. In particular, the Great Paris Region is divided into 1305 emission and reception zones with the same number of zone centroids. The 1305*1305 origin – destination matrix concerns the trips using public transportation at the morning peak time at 2008. If we exclude the 84 367 intra-zone trips (with the same origin and destination), we simulate a typical hour with 1 146 976 trips using a public transportation mode.

Even though the OD matrix correspond to the public transportation trips made in the most loaded period of the day, the morning peak hour, the results show only minor congestion for the worst case scenario in 2008. We wish to demonstrate that with a significantly greater passenger flow, as long as the demand is lower than the overall system capacity, the behaviour of the CapTA model is reasonable. Indeed, we choose to multiply the initial Origin – Destination Matrix with a 1,3 factor. That could make reference to a hyperpeak flow within the morning peak, but it is mainly used to show the validity of the results for high transport flows.

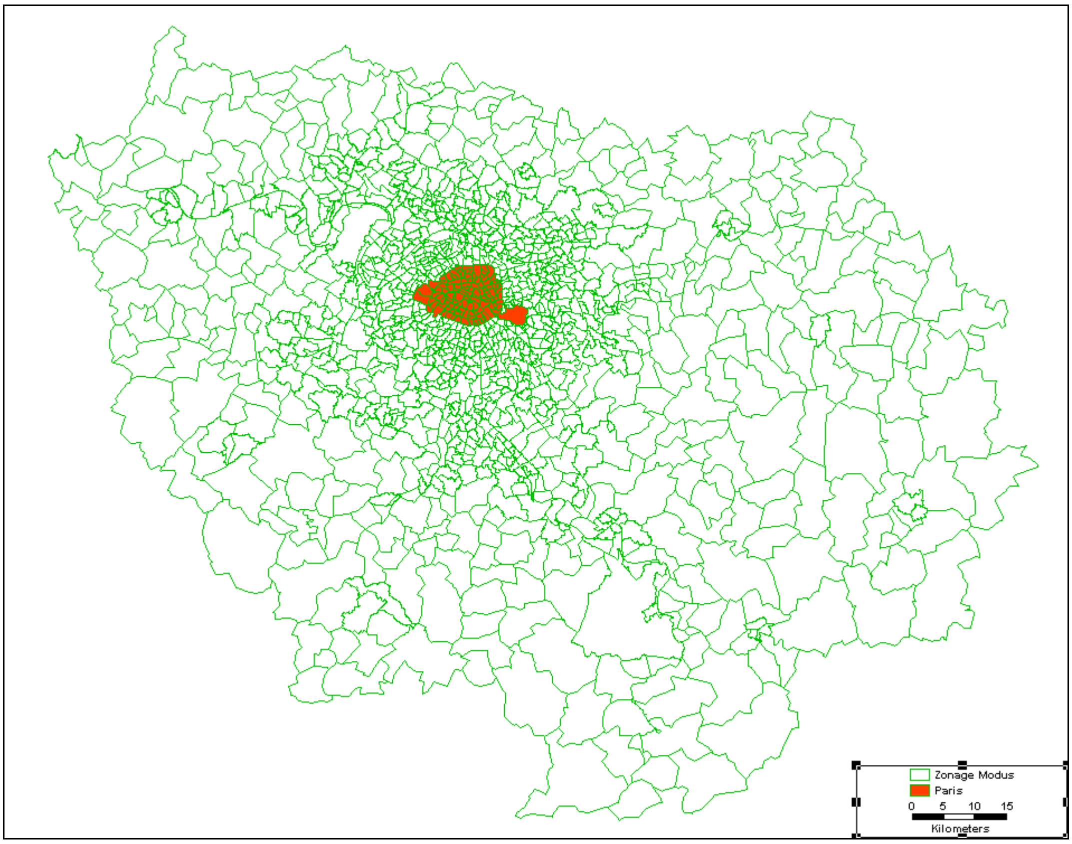

Figure 2: The map of the zones of the Greater Paris Region with Paris in the centre

3 The Transit Supply in the Greater Paris

The Greater Paris is characterised by a dense transit system with a great diversity of modes and types of services. From the metro- and bus-dominated central area, passing from the RER who cut across the agglomeration to connect the suburbs between them and with Paris, to the standard commuter rail connecting the 6 central Paris train stations to the near and distant suburbs, we can observe a significant variability in the frequency and the commercial speed of the services. The following table recapitulates the main characteristics of the Greater Paris transit system by transport mode.

Tableau 1 : The characteristics of the Greater Paris transit system

Transit Mode	Lines	Station or stops	Total length (km)
Rail	13	443	1401
Metro	16	301	215
Tram	4	71	42
Bus	1372	30100	23263
VAL	2	8	11

The transit supply used in the CapTA model is based on the data provided by DRIEA, while doing the necessary transformations. The service timetable from the initial data was used in order to estimate the hourly frequency of each transit service. The in-vehicle travel time of the transit arcs was calculated on the basis of the actual length of the transit links within the network and an in-vehicle travel time ration per transit route provided. Further modifications were made to in order to adapt the travel time of the transit services to the actual station to station travel times.

The transit network is characterised by a multitude of different rolling stocks. There are at least 17 types of trains with different compositions and interior design characteristics. The same occurs in the metro, with 7 types of vehicle on rail or tyre. As long as the buses and coaches are concerned it is not simple to define the actual models circulating. However, we have defined 7 categories of road vehicles with average characteristics (Chandakas, 2012). We assigned one rolling stock on each one of the transit routes of the Greater Paris network. An additional table was created with the characteristics of the transit services: capacity, headway, dwell time and number of passenger stream for the passenger exchange at stations. Figure 3 illustrates the line capacity per transit mode on the central section of the Greater Paris transit network. The green and red lines designate the commuter rail and RER, while the blue line corresponds to the metro lines.

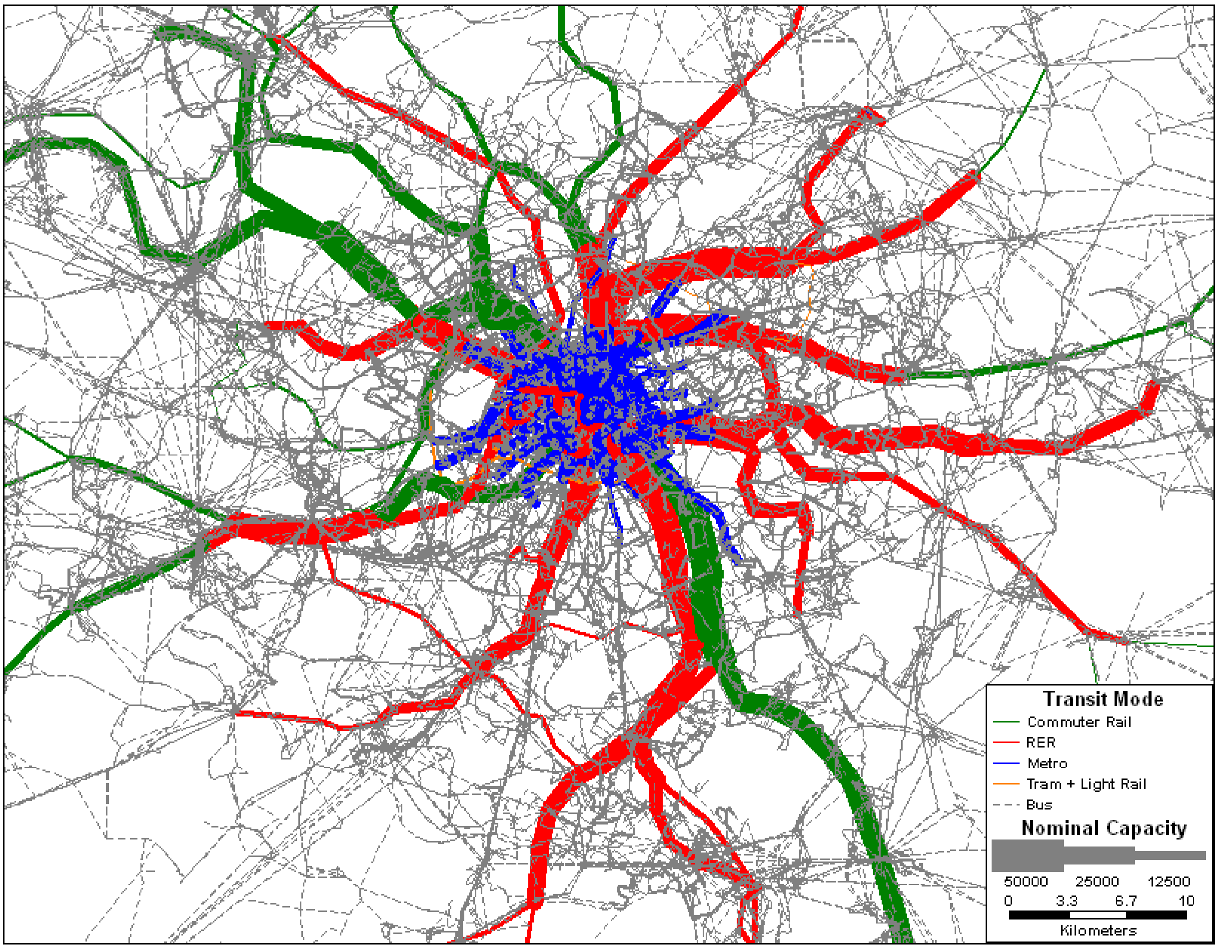

Figure 3: The total capacity of the transit lines, by transport mode (central sector)

The final service network is transformed into the calculation network for use in the transit assignment. The modifications mainly concern the guided transport modes (rail, metro, tramway and VAL) and their stations. The transit lines are identified – as presented in chapter ..., acting as a basic component for the simulation – and the station platforms for each direction are distinguished by an additional platform access/egress arc between them and the station concourse level. When the simulation included comfort on the buses, service legs are added to the calculation network.

Tableau 2: The main characteristics of the modelled transit network

Transit Supply	
Directional Transit Lines	95
Transit Services (all modes)	4742
of which affected to transit lines	259
Station Platforms	1889

Zones	1305

Furthermore, the dual representation of the transit services is achieved by creating the transit subgraph; a line leg is added between each station couple within the line. Tableau 3 resumes the service network used as input for the assignment model. We observe that by substituting the line legs to the service arcs on the transit lines, there is only a slight increase of the link elements (+3,8%). In other words, some 19 560 transit arcs (boarding, in-vehicle sojourn and interstation and alighting arcs) are replaced by 30 729 line legs (+57%) that connect the station couples within each transit line. The number of line legs is sensible only to the number of stations on a transit line, whereas the arcs also depend on the number of alternative transit services within a transit line.

Tableau 3: The graph elements of the service network

Service Network Elements	
Initial Nodes	17 413
Service Network Nodes	159 447
Initial Arcs	64 558
Standard Arcs Representation	296 525
Line Legs	30 729
Total Legs and Arcs (for assignment)	307 694

4 Simulation Characteristics and Model Variants

The Greater Paris transit network was simulated by 4 variants of the CapTA model. The purpose is to investigate how the various effects contribute in the passengers' path choice and the traffic state of the transit network. These model variants are defined as follows:

- **UC:** It corresponds to the unbounded model, where no capacity constraints apply. The passenger flow under these free-flow conditions is assigned to the best hyperpath, or the preferred set of paths

- **CNC:** This variant includes the total capacity and platform occupancy constraints, modelled with the transit bottleneck and the frequency modulation models, as described in Leurent et al (2011). Simple applications, such as in Leurent et al (2012) suggest there is a trade-off between waiting time on the platform (due to insufficient vehicle capacity) and in-vehicle comfort.

- **CWFC:** It includes all the capacity constraints included in CapTA, namely, the total capacity and frequency modulation for guided transit (rail, metro, tramway) and the in-vehicle comfort for all the transit modes (guided transit and buses). The penalty factor for in-vehicle comfort is fixed for any density of on-board standing passengers

- **CWVC:** Equivalently to the previous variant, all capacity constraints are applied. However, the in-vehicle comfort factor is variable, increasing linearly from the first standing passenger until the standing density of crush capacity. It is considered the central variant of the model. If not stated otherwise, the results of the bounded model correspond to the CWCV model variant.

The main global parameters in a CapTA simulation concern the penalty factor to be considered in the generalized cost function. Indeed, the generalized cost of a path will be the sum of the actual travel times for each arc in the path weighted by a penalty factor which depends on the importance of that element to the user's trip. In the simulation we distinguish four different types of cost components: access – egress, transfer, waiting and in-vehicle. Each one has a different penalty factor, according to the following table:

Tableau 4 Penalty factors

Penalty factors of cost components	
Access and Egress	2
Transfers	2
Waiting in platform	2
In-vehicle comfort	Fixed 1,8 or Variable 1,2-2

When dealing with the in-vehicle comfort, we assume two distinct comfort states, standing and sitting. A fixed comfort penalty will penalize the trip for a medium load, contributing to a dispersion of the passenger flows to many transit paths. The fixed comfort coefficient is equal to 1,8 of the in-vehicle seating time, as suggested in Liu (2009). However, some researches (TRB, 2003, STIF, 2007) suggest that the penalty coefficient depends on the density of standing passengers. Therefore, we assume a linear function of the standing penalty factor $\chi^{r}_{za}(d_a)$ where d_a is the density of standing passengers for a certain trip segment a. The CWCV variant adopts a standing penalty coefficient varying from 1,2 (for $d_a = 0$) to a maximum of 2,0 (for $d_a = 4\,p/m^2$).

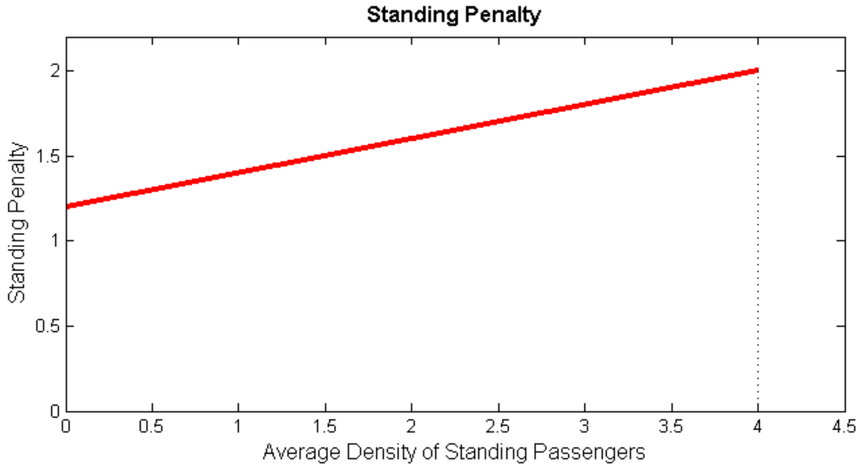

Figure 4 The standing comfort penalty as a function of the density of standing passengers

Furthermore, since we want to submit the CapTA model into a bigger passenger flow, we have added an OD matrix multiplier as a simulation parameter. By setting that to 1,3 we multiply all the origin – destination passenger flow by the same coefficient.

The model was coded in C++ using an object oriented approach. The simulation runs on a 2,66 GHz Intel PC with 4 GB of RAM. The average run time per iteration amounts to 8 minutes for the unbounded model (UC). Each iteration in the capacitated model (CWCF and CWCV) – extending the in-vehicle comfort also to the bus services – requires about 23 minutes. Within an iteration, the in-vehicle comfort for the buses takes additional 6 minutes and for the guided transport, 7 minutes, for a total computing time of 13 minutes (of the 23 minutes of an iteration) for treating in-vehicle comfort.

The convergence is calculated by the average gap of the passenger flows on each arc. Figure 5 illustrates the convergence of the model variants, CNC, CWCF and CWCV. An acceptable level was reached after 50 iterations with a gap reduced to 1‰ of the initial value. The inclusion of comfort leads to a quicker convergence.

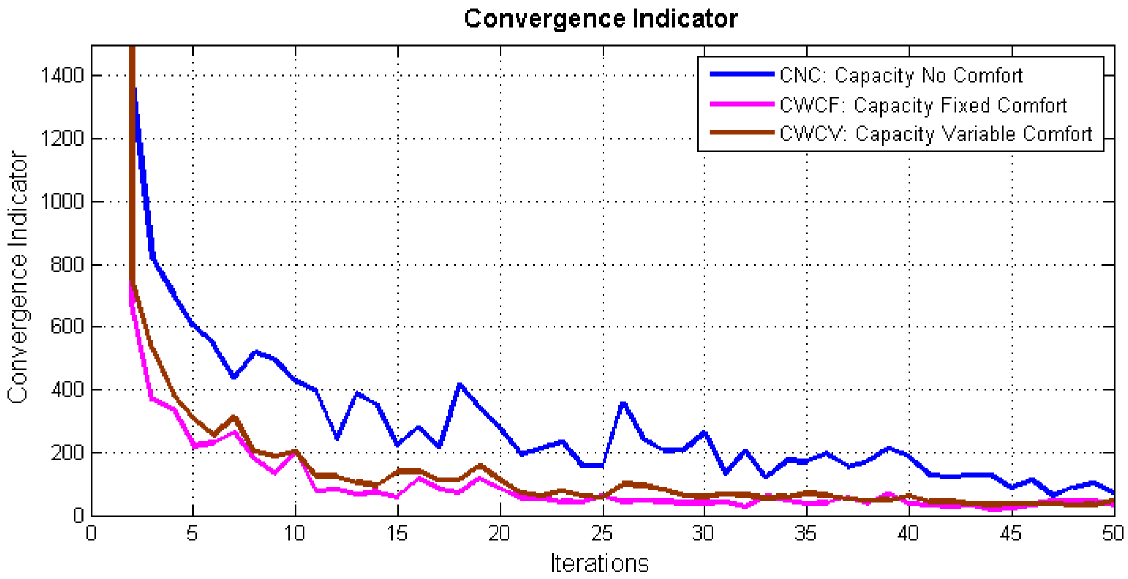

Figure 5 Convergence Indicator of the bounded model variants

5 Passenger flows on the transit network

The passenger flow is the main output of the transit assignment model. The unbounded variant (UC) corresponds to the route itineraries, without congestion, under free-flow conditions. In other words, it corresponds to the best hyperpath or the preferred set of paths for the passengers. Some structural lines, such as the main commuter lines, RER A (east-west) and RER B (north-south) are particularly loaded, with flow to capacity ratios that can reach the 1,7 (or 100 000 passengers per direction per hour) for the central section of the RER A. That corresponds to an excess of 42000 passengers at the most loaded hour compared to nominal capacity and normally they have to find an alternative route if capacity constraints are considered.

For the bounded variants (CNC, CWCF, CWCV), the route choice takes into consideration the effect of the passenger flows on the generalized cost and the path choice due to the local capacity constraints: the vehicle and route total capacity, the seat occupation and the vehicle capacity of the station track. Figure 6 illustrates the passenger flows on the network (line width) and the flow to capacity ratio (colour) on the guided mode lines for the CWCV variant. In light and dark green are the line segments with a flow up to 75% of total capacity and the yellow and orange the arcs designate a flow to capacity ratio comprised between 75% and 90% and 90% and 100% of the line’s capacity respectively. In purple we illustrate the links where the hourly passenger flow exceeds the hourly capacity. However, for the CWCV variant these segments are limited (9 out of 1750) and the highest flow exceeds line capacity by only 3,75%. It is apparent that by applying the capacity constraints, the passengers faced with additional waiting time, due to the transit bottleneck model and in-vehicle discomfort, choose to transfer to alternative paths with lower congestion.

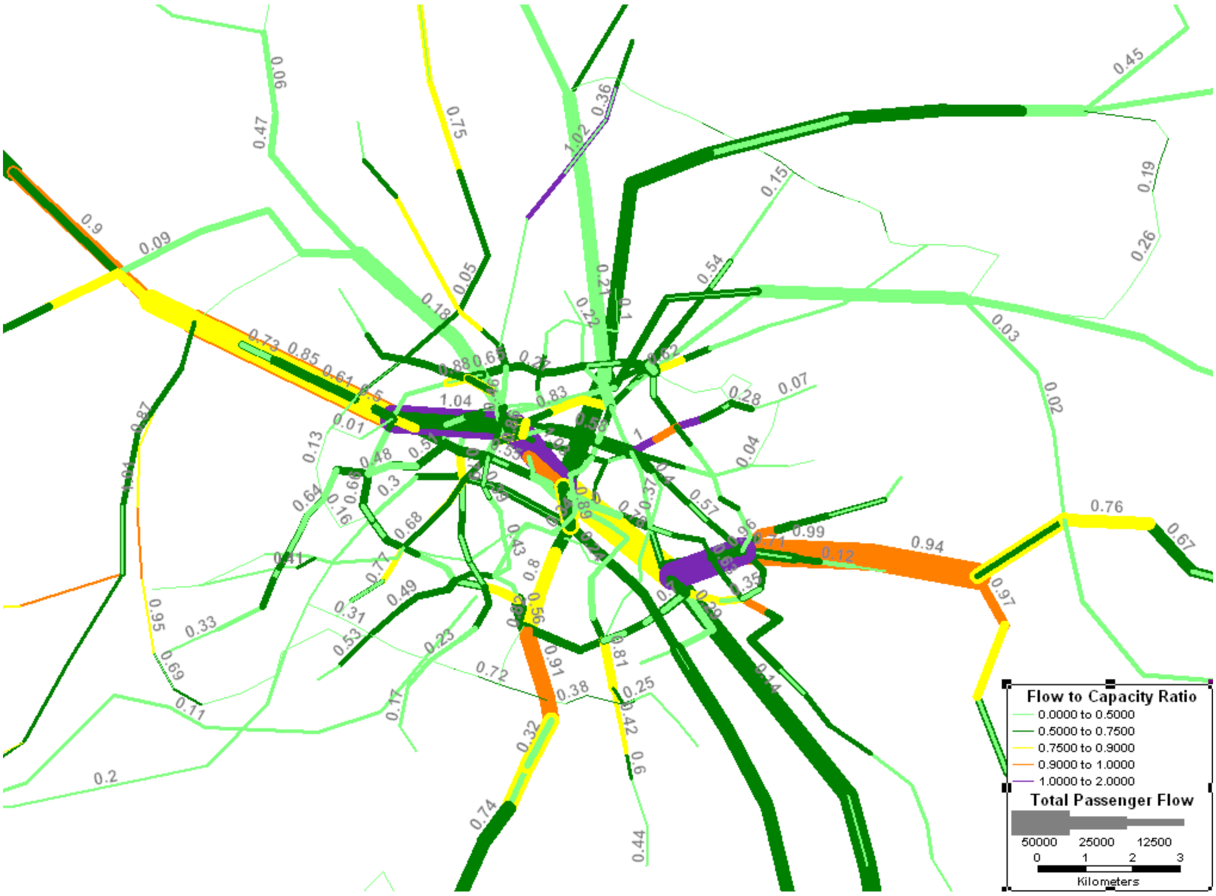

Figure 6: Passenger flows and the ration between flow and capacity for the bounded model

Figure 7 illustrates the number of rail arcs (light rail, metro and commuter rail) by 5% flow-to-capacity ratio increments for the four model variants. We observe that the relaxation of the capacity constraints at the network flow assignment results for the bounded models (CNC, CWCF and CWCV) in some arcs being loaded with a passenger flow exceeding their nominal capacity. For the CNC model the distribution of the arcs is quasi-identical to the unbounded variant until the 80% flow-to-capacity ratio and a significant number of arcs exceed nominal capacity (48 out of 1750 with the most loaded arcs exceeding capacity by 8%). For the unbounded model the oversaturated arcs are more (58) and their load more severe, reaching 1,78 of the nominal capacity. For the models with comfort these number are lower (18 and 9 for the CWCF and CWCV respectively), demonstrating that comfort plays an important role in driving passengers to alternative routes.

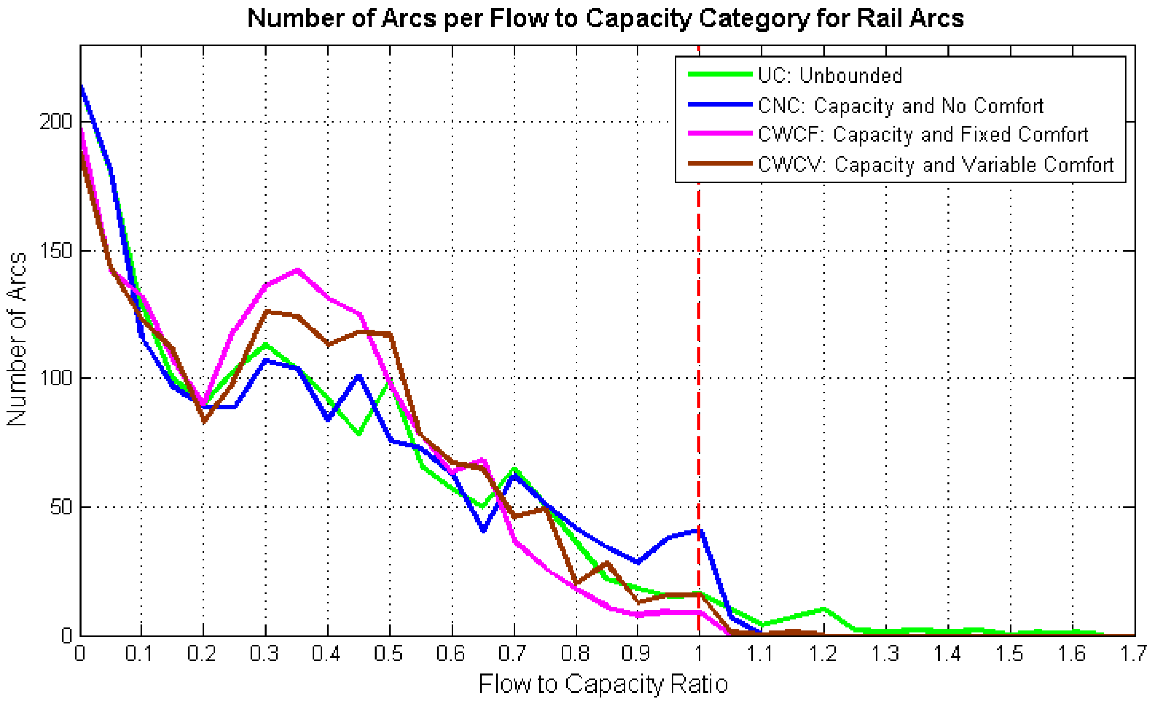

Figure 7: Number of Arcs in relation to flow/capacity ratio

Furthermore, by comparing the distributions of the unbounded (UC) and CNC models, we observe a similarity for low and medium flow-to-capacity ratios, until the 80%. As for the CNC model variant, a large number of arcs – compared to all other variants – lies between 80% and 100% of the nominal capacity, suggesting that it successfully reduces the flow of oversaturated arcs, just below their nominal capacity. As with the comfort variants (CWCF and CWCV), the distribution of the arcs has a peak around 35% of the capacity, reflecting the seat capacity. Indeed, the seat capacity corresponds to 40-60% of total vehicle's capacity for rail, 20% for metro and 30% for tramway. Comparing the two comfort variants, we observe higher concentration of arcs around the seat capacity for the CWCF and lower concentration at high flow-to-capacity ratio, than the CWCV model. That steams for the fixed penalty discomfort of the CWCF variant, penalizing all the comfort level, rather than tolerating low standing densities with a variable coefficient such as in CWCV.

6 The operation of transit routes under capacity constraints

The vehicle flowing along a fixed track considers the effect of passenger flows according to the track occupancy and frequency modulation model, as indicated in Leurent et al (2011). The model assumes that the operative frequency, ϕ_z, of a transit route at a station depends on the dwell time (and therefore the boarding and alighting flows) and the safe separation time between two following vehicles for all vehicles using the track occupancy of all the transit routes sharing the track infrastructure.

The simulation of the Grand Paris transit network allows investigating the behaviour of the bounded variants. We can make two observations with concordance to the theoretic model. First, due to the initial "free-flow" passenger flows, the frequency modulation happens abruptly at the first intermediate traffic state calculated, due to the initial "free-flow" passenger flow. As we approach the stationary point, the route frequency oscillates around a certain value and seems to approach a stationary point.

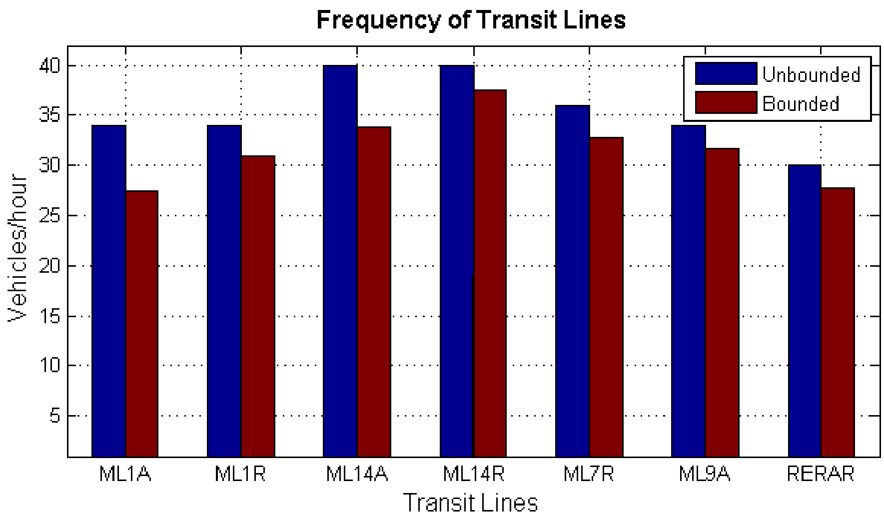

Figure 8: The initial and modulated frequency at the terminal for some rail lines in the Greater Paris transit network.

The frequency modulation is also affected by the network externalities. While the frequency is initially modulated for some routes, the existence of efficient alternative paths leads to reestablish the nominal frequency when traffic equilibrium is reached. Furthermore, for a network with good connectivity such as the Paris metro, some lines with multiple transfer stations may see the passenger flow change from an iteration to another until the path flows converge. Therefore, the final path flows may induce a frequency modulation that takes place at a different station than initially.

The simulation on the Grand Paris transit network demonstrates that a high duty network with massive passenger flows is subject to frequency modulation along some of its transit routes. As illustrated on Figure 8, the hourly frequency drops considerably on some structural routes for the bounded CWCV variant. Line 1 of the Paris Metro shows a reduction of its hourly frequency from 34 veh/hour to 27,4 veh/hour for the eastbound and 31 veh/hour for the westbound service, while line 14 faces a reduction by 6-15%, from a nominal frequency of 40 veh/hour to 33,9 veh/h for the westbound and 37,4 veh/h for the eastbound service.

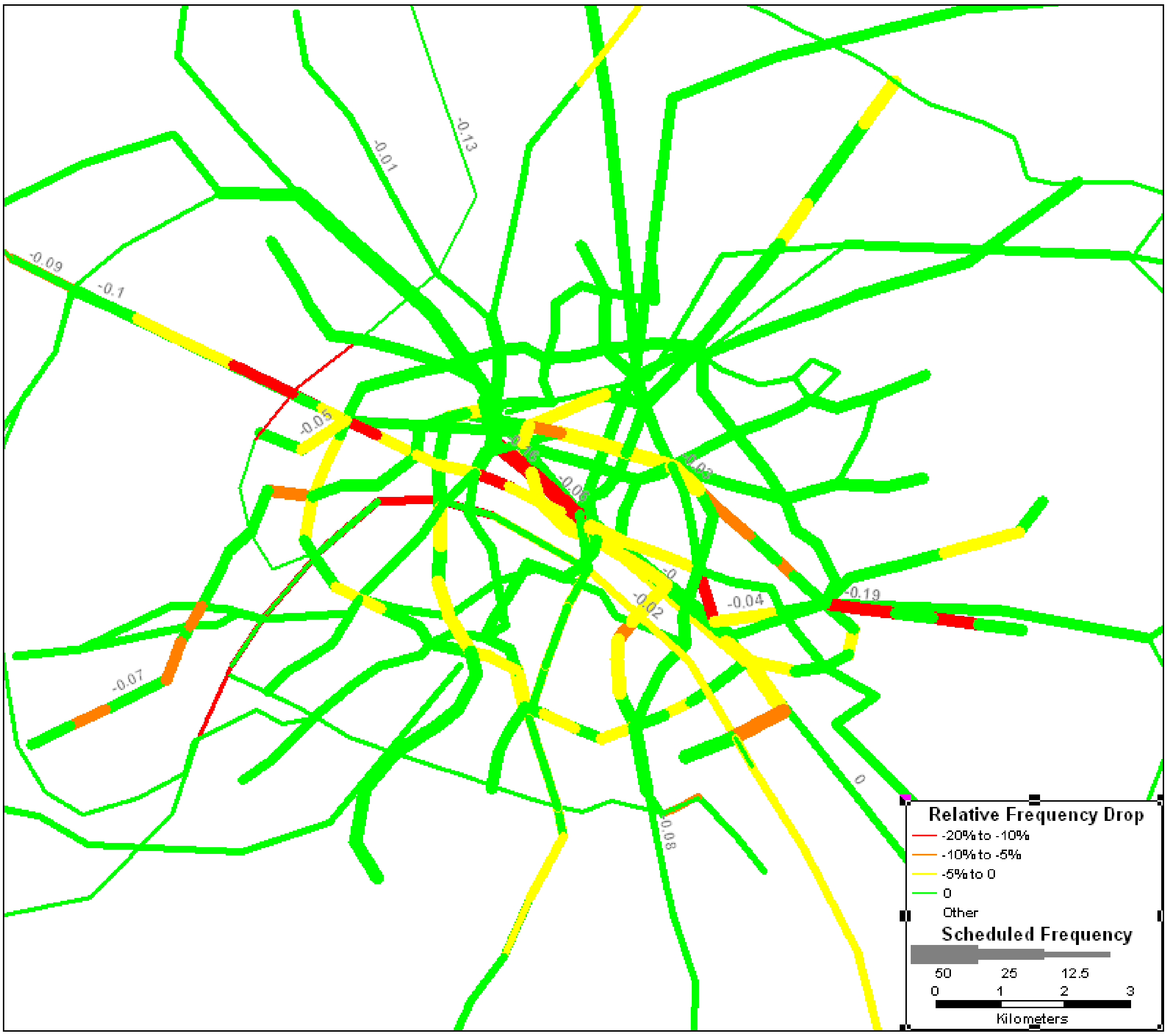

Figure 9 The relative frequency drop due to the frequency modulation in the central sector of the Greater Paris

In Figure 9 we illustrate the relative frequency drop in the central sector of the Greater Paris transit network. While the great majority of the structural transit lines are not affected, a reduction up to 5% of their initial frequency can be observed in lines such as Line 6, 7 and 9 (depending on direction) and the RER C. However, the most sensible lines to frequency modulation, with a reduction over 5% from scheduled frequency are mainly the metro lines.

The RER A eastbound service faces a reduction of its nominal frequency by 7,7% from 30 veh/h to 27,7 veh/h. However, other than the direct reduction of the frequency, it is important to note the secondary effects of the frequency modulation, such as the reduction of the seat and passenger's capacity offered downstream and the increase of the passengers willing to board each train. Indeed, the service capacity on the RER A eastbound service is reduced east of La Defense by 7,8% with a capacity loss downstream of approximately 4500 passengers and 1400 seats per hour. That corresponds to the equivalent capacity of 1,7 duplex high-capacity trainsets.

7 Impacts on users

The average generalized cost on the transit network includes the waiting and in-vehicle time as well as the walking time needed for a transfer and the access-egress time. In Tableau 5, we resume the average generalized time for the model variants and further detail their elements. We analyse the composition of the average optimal generalized time (GT) for the CWCV model variant. By waiting time we consider the initial waiting time for the access to the network and any further waiting time due to transfer, which corresponds to the 29,1% of total GT. The most important element is the in-vehicle travel time with 41,5% of total GT, while the transfer is only 5,6% and the access – egress time forms the 23,8% of the total GT.

Tableau 5 : Average generalized time (in minutes) on the Greater Paris transit network

Model	Optimal TT	Actual TT	Perceived WT	Perceived IVTT	Perceived Transfer T	Perceived Access-Egress	Nb of Transfers
UC	61,56	40,63	18,79	23,10	3,96	15,71	1,42
CNC	62,73	41,40	19,44	23,65	3,98	15,67	1,44
CWCF	69,96	41,77	20,02	29,02	3,97	16,95	1,35
CWCV	68,45	41,70	19,90	28,40	3,88	16,27	1,35
%diff CWCV-UC	11,2%	2,63%	5,9%	23%	-2,04%	3,6%	-5,13%

We observe that in the CWCV variant the average generalized time for a journey on the network increases by 11,2% in comparison to the unbounded model (UC). The in-vehicle travel time faces a significant increase (by 26% and 23% for the CWCF and CWCV variants) in comparison to the UC (and the CNC) variant since the former variants include in-vehicle discomfort penalties. After all, 3/4 of the increase of the generalized travel time is attributed to the in-vehicle comfort. On the other hand, the increase in the waiting time is modest, reflecting the sufficient overall capacity of the transit network. That value is a weighted average of all the transit modes and includes the buses where no capacity effects are being applied (except in-vehicle comfort). However, the increase in the waiting time (in the CWCV variant) implies that approximately 14 800 hours are spent in additional queuing over the morning peak hour.

Excess passenger flows have an impact to the waiting time on the transit routes. However, many transit lines have some available capacity, suggesting that overall capacity of the transit network is sufficient. Congestion is concentrated on a number of lines, inducing a considerable increase in the waiting time. The average waiting time of the metro line 1 eastbound service increases by 14% (mainly due to the reduced capacity from the frequency modulation), while for the southbound line 11 increases by 22% and for both directions of line 14 there is an increase around 3%. These effects are considerable, as they correspond to an additional waiting time of 230h for the users of eastbound line 1 and 130h for the users of southbound line 11, during the morning peak hour.

Applying the capacity constraints to a simulation modifies significantly the distribution of the passenger flows on the transit lines. Figure 10 (left hand side) illustrates the total number of passengers travelling on each line during the simulation period for the unbounded (UC, in blue) and the bounded model (CWCV, in brown). We observe a reduction of the passenger flows on the second case. At the right hand side, the effect on the waiting time is illustrated, where passengers willing to board at the platform face the available capacity. The increase in the average waiting time is moderate (until 5%), except the eastbound RER A (+76%), the southbound M13 (+19%), M11 (+22%) and the eastbound M1 service (+14%). That suggests that a transit assignment model with capacity constraints, such as CapTA, succeeds to spread the passenger flows to alternative paths (if they exist), while it can evaluate the effect of punctually insufficient capacity.

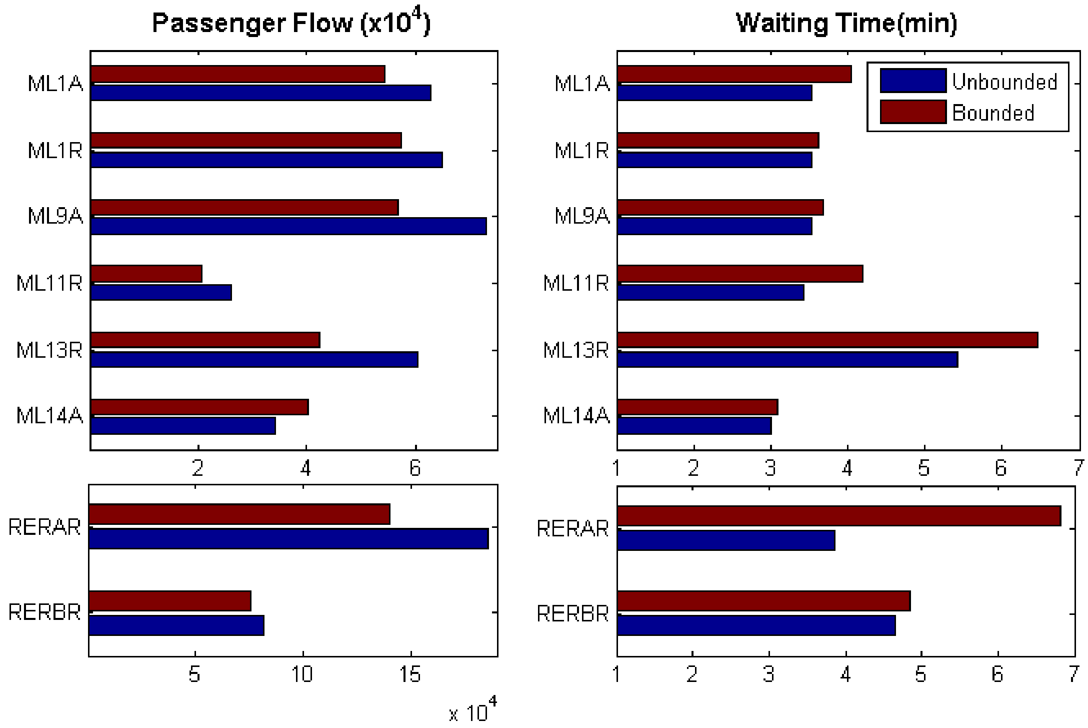

Figure 10: Passenger Flows and Average Perceived Waiting Time on selected lines for the unbounded (UC) and bounded (CWCV) model

8 Impact of in-vehicle comfort

As stated previously, the generalized time (and the path choice) seems to be strictly impacted by the in-vehicle comfort. Since the current transit network offers sufficient overall capacity, the transit bottleneck exists only punctually, at certain station and lines, indicating a semi-congested traffic state (where at a platform at least one route is congested, while not all the available capacity is used). For these reasons, the in-vehicle comfort, which impacts the bus as well as the rail services, plays a more important role on the path choice. The comfort allocation model measures the number of standing passenger as well as their average density, in order to designate various levels of discomfort.

The impact of the in-vehicle comfort is significant. Standing passengers can be found in the tramlines, the metro, the RER and CR lines. However, due to the linear discomfort function of the central model variable (CWCV), the additional cost depends on the density of the standing passengers. The additional cost of an average trip (for sitting and standing passengers) on the metro lines varies from 27% of the average actual travel time for line 10 to 68% for the heavy-loaded line 14.

While that value is high for line 14, the average standing time for a passenger varies only from 2,5 to 4,5 minutes according to the direction. Figure 11 illustrates the average sitting time for a trip and the average time a passenger travels standing for the UC and CWCV model variants. The impact of standing discomfort is higher for longer lines, such as M8, where if a passenger stands at any moment during the trip, he will stay in that comfort state on average 7,5 minutes (CWCV model) before sitting or getting off. The figure also demonstrates that the average sitting time increases in the case of the CWCV model (where passengers are sensible to in-vehicle comfort). That is a straightforward result, though it can be attributed both to the reduced number of transfers (-5%), since the transfer risk incites them to stay longer if seated, but also to reduced pressure for getting a seat. Therefore, the combination of fewer standing passengers due to the bounded passenger flow at the line model, and an equivalent number of sitting passengers that exit each station, since those who succeeded to sit may have boarded when the total capacity effect didn’t affect the boarding flows, increases the probability of getting a seat at any moment of the trip.

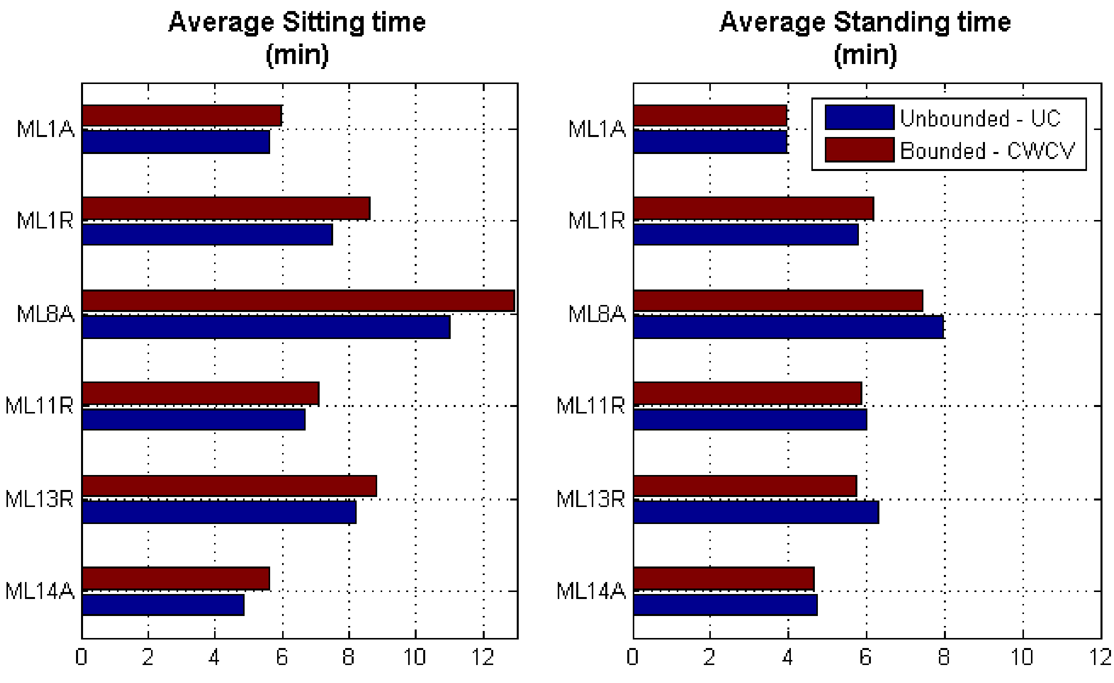

Figure 11: Average Sitting and Standing time on selected lines for the unbounded (UC) and the bounded model (CWCV)

9 Conclusion

The paper offers a description of the CapTA transit assignment models for capacitated networks together with its application to the Great Paris Region. It is based on the line model as a framework to represent a variety of features and phenomena in a transit system, both of physical and microscopic nature. The bi-layer network representation allows focusing on a quasi-microscopic level when considering the flow loading and line costing process at a line level, while maintaining the macroscopic level for the passenger flow assignment to the transit network. The framework is essentially systemic and modular: some parts of it may be replaced by mode appropriate sub-models, for instance about track occupancy, or the interaction of access and egress flows in station dwelling.

The transit network of the Grand Paris Region with 4 tramlines, 14 metro lines and 13 commuter rail lines and a central core with line redundancies offers an ideal field for applying a transit assignment model with capacity constraints. Massive passenger flows are concentrated on main north-south lines, the RER B and metro line 13 and east-west axes such as the RER A and metro line 1 and 14. The bounded model variants (CNC, CWCF, CWCV) manage to disperse the passenger flows transiting from the congested lines to alternative paths, whereas the flow to total capacity ratio exceeds 100% only punctually, for certain line segments, by no more than 3,7% of the line capacity (for CWCV).

The high passenger flow impacts the operation of the transit routes and the frequency is modulated in most of the metro lines of the Paris network. The frequency is reduced up to 15 and 19% for the metro lines 14 and 1 respectively, inducing secondary effects along the lines due to the reduced downstream capacity and the increased passenger stock for each vehicle. On the passenger side, these effects contribute to the increase of the average waiting time up to 14% and 22% for the line 1 and 11 respectively. Even though, the increase seems moderate, it corresponds, only for eastbound direction of line 1 to additional 230 actual hours waiting during the morning peak hour. In addition to longer waiting times, the passengers face in-vehicle discomfort when they travel standing. The average travel time a passenger stands depends on the topology and congestion of the line and therefore lines without excessive passenger flows may have the longest standing time, such as line 8 where it takes values from 5,5 to 7,5 minutes according to the direction.

The computation time can be reduced if we treat in parallel order the multiple independent processes treated sequentially. Other than the computation efficiency, the model, being modular, can be further developed. A more detailed interaction may be considered between the boarding and alighting flows, the in-vehicle passenger load and passenger stock at the platform as well the vehicle's and platform's architecture and how these components influence the dwell time. Further microscopic phenomena can be added, such as a willingness to board an overcrowded vehicle, if the available capacity is insufficient and the passenger stock is too important, thus affecting the in-vehicle discomfort of on-board passengers. Finally, additional models may be added, first, within the line model, by considering the effect of general traffic conditions to the vehicle's journey time and second, by developing a station model to capture the effect of passenger flows on the quality and travel time of transfers and access-egress trips.

Version	Date	Type	Remarques
0	24/05/2012	Rédaction	Première version
1	19/09/2012	Rédaction	Modifications depuis ETC_IDF
2	16/10/2012	Correction	Correction et mise en cohésion

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Appendix – Traffic state

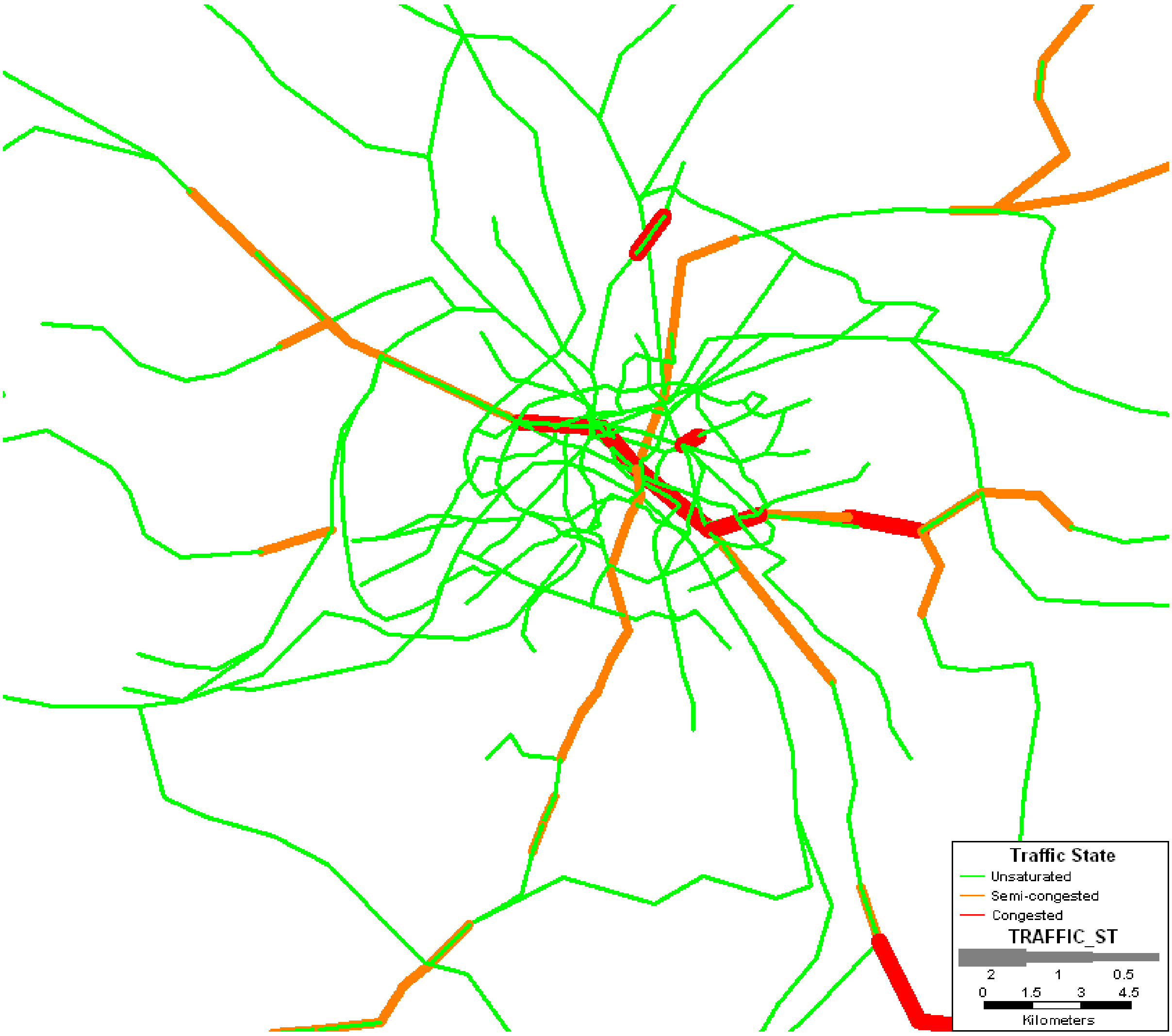
Through the transit bottleneck model (in Leurent et al, 2012) we may define three distinct traffic states, according to the saturation of the services, as follows:

I. **Uncongested regime**; passenger flow is weak and does not saturate any capacity constraint.

II. **Semi-congested regime**: at least one service is saturated, while others have still some capacity available to accommodate the additional flow. The access – egress flow is assigned to the alternative services within the reference period H . Both the expected waiting time and the in-vehicle travel time are increased.

III. **Congested regime**: all the services are saturated. The access – egress flow x_{is} cannot be served within the reference period, H . Insufficient capacity results in a significant increase in the expected waiting time by access – egress pair.

Figure illustrates the traffic states on the guided transit modes (rail, metro, tramway) on the Greater Paris network for the CWCV model variant.


Traffic State
Unsaturated
Semi-congested
Congested
TRAFFIC_ST
2
1
0.5
0
1.5
3
4.5
Kilometers